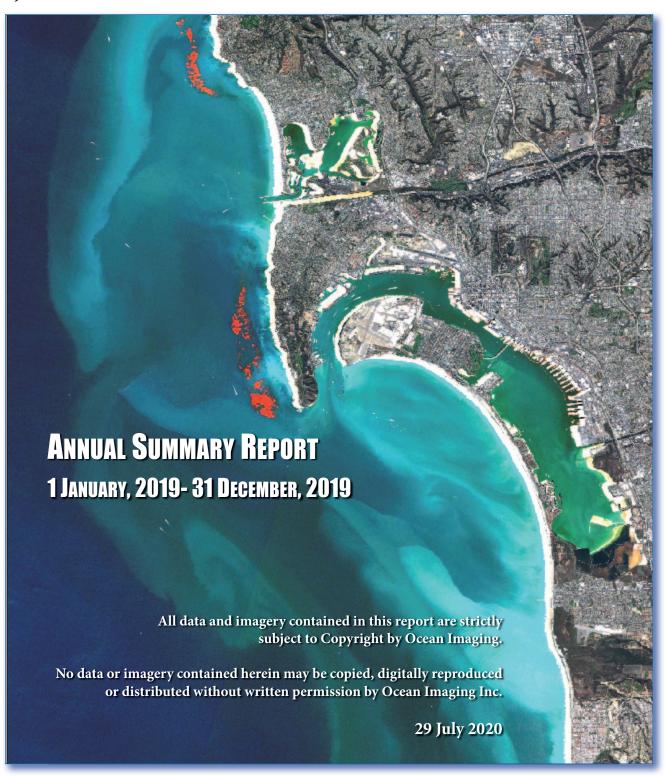
SATELLITE & AERIAL COASTAL WATER QUALITY MONITORING IN THE SAN DIEGO / TIJUANA REGION

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1. INTRODUCTION AND PROJECT HISTORY

Ocean Imaging Corp. (OI) specializes in marine and coastal remote sensing for research and operational applications. In the 1990s, OI received multiple research grants from NASA's Commercial Remote Sensing Program for the development and commercialization of novel remote sensing applications in the coastal zone. As part of these projects, OI developed methods to utilize various types of remotely sensed data for the detection and monitoring of storm water runoff and wastewater discharges from offshore outfalls. The methodology was initially demonstrated with collaboration of the Orange County Sanitation District. The NASA-supported research and demonstration led to a proof-of-concept demo project in the San Diego region co-funded by the EPA in 2000. Those results led, in turn, to adding an operational remote imaging-based monitoring component to the San Diego region's established water quality monitoring program, as stipulated in discharge permits for the International Wastewater Treatment Plant and Point Loma outfalls. The project was spearheaded by the State Water Resources Control Board (SWRCB), EPA Region 9, and continues to be jointly funded by the International Boundary Waters Commission and the City of San Diego (City).

The first phase of the project was a historical study utilizing various types of satellite data acquired between the early 1980s and 2002. The study established, among other findings, the prevailing near-surface current patterns in the region under various oceanic and atmospheric conditions. The current directions were deduced from patterns of turbidity, ocean temperature and surfactant slicks. In some cases, near-surface current velocity could be computed by tracking recognizable

color or thermal features in time-sequential images. The historical study thus established baseline data for the region's current patterns, their persistence and occurrence frequency, and the historical locations, size and dispersion trajectories of various land and offshore discharge sources (e.g. the offshore outfalls, Tijuana River, Punta Bandera Treatment Plant discharge in Mexico, etc.).

In October 2002 the operational monitoring phase of the project was initiated. To date, this work utilizes 500m resolution Moderate Resolution Imaging Spectroradiometer (MODIS) color imagery (available near-daily), 1000m resolution chlorophyll and Sea surface Temperature (SST) imagery, 1100m resolution AVHRR SST imagery, 750m resolution Visible Infrared Imaging Radiometer Suite (VIIRS) chlorophyll and SST imagery, 300m resolution Sentinel 3 color and thermal imagery (available daily), 10m resolution Sentinel 2 multispectral imagery (available 2-4 times per week), 27m & 60m Landsat Thematic Mapper TM5, TM7 and Landsat 8 OLI/TIRS color and thermal imagery (each available approximately every 16 days) and 6m resolution SPOT 6 and Spot 7 each available every 4-5 days). More information on these satellites and sensors is provided below. Up until 2010, the project relied heavily on acquisition of multispectral color imagery with OI's DMSC-MKII aerial sensor and thermal infrared (IR) imagery from a Jenoptik thermal imager integrated into the system (see details in the "Technology Overview" section). These aerial image sets were most often collected at 2m resolution. The flights were done on a semi-regular schedule ranging from 1-2 times per month during the summer to once or more per week during the rainy season. The flights were also coordinated with the City of San Diego's regular offshore field sampling schedule so that the imagery was collected on

the same day (usually within 2-3 hours) of the field data collection. Additional flights were done on an on-call basis immediately after major storms or other events such as sewage spills. In late 2010 OI negotiated a special data collection arrangement with Germany's RapidEye Corporation and this project began utilizing their multispectral imagery in lieu of most of the aerial DMSC image acquisitions. RapidEye maintains a unique constellation of 5 satellites which deliver 6.5 m resolution multispectral imagery. In 2014 Black Bridge Inc. took over the management and resale of RapidEye data and in 2016 Planet Labs, Inc. acquired Black Bridge and the RapidEye fleet of 5 satellites. Subsequently, OI renegotiated with Planet Labs to preserve the original structure and pricing for the continued purchase and use of RapidEye imagery. Unlike other single high-resolution satellites, the multi-satellite constellation enabled revisits of the San Diego region on a near-daily basis. Another advantage of using this imagery is the much larger spatial coverage available with each data set that was not possible using the aerial sensor. The use of satellite as opposed to aerial data also enables a more regionally contiguous monitoring of events affecting the target areas. In October of 2019 Planet Labs stopped delivering RapidEye data in preparation for the decommissioning of the satellite constellation in late 2019. In October through December of 2019 OI assessed the data from a few different Plant Labs-operated satellites. None were deemed of high enough quality (high signal to noise ratio and radiometric fidelity) to effectively detect and reliably map both the outfall surface signatures and the Tijuana River plume. The RapidEye satellite constellation was eventually decommissioned by Planet Labs in April of 2020. Subsequently OI secured the regular acquisition of SPOT 6 and SPOT 7 satellite imagery covering the same geographical area beginning in 2020. These data are discussed in more detail below.

In 2012 OI also began operationally providing the City with a suite of additional oceanographic products daily through the City's EMTS web-based GIS "BioMap" Server and continued expanding the product selection and delivery through 2014 and into 2015. In 2016 the Biomap project was discontinued, however Ocean Imaging continued the development of imagery and data services so that the data are compatible with the City's ESRI ArcGIS online map server. The intent was to deliver all the remote-sensing and model-derived products to the City's end users by fall of 2017. This ongoing effort is discussed in more detail in latter sections of this report. The original add-on products ranged from atmospherically corrected satellite images of sea surface temperature (SST) and chlorophyll to radar and model-derived surface current fields and since have been expanded to include ocean currents and mixed layer depth data products derived from the U.S. Navy's Hybrid Coordinate Ocean Model (HY-COM – www.hycom.org). Also added as a full-time operational data set in 2017 was satellite imagery from the Sentinel 2A and 2B satellites. In fall of 2018 data from the Sentinel 3A and 3B satellites were added to the suite of data products. Therefore, as of late 2018, data from all the Sentinel satellites/sensors have been provided as regular image products as part of the coastal and outfall monitoring effort.

This report summarizes observations made during the period 1/1/2019 – 12/31/2019.

2. TECHNOLOGY OVERVIEW

2.1 OI uses several remote sensing technologies to monitor San Diego's offshore outfalls and shoreline water quality. Their main principle is to reveal light, heat or microwave signal patterns that are characteristic of the different discharges and water turbidity. Most often this is

due to specific substances contained in the effluent but absent in the surrounding water.

2.1 Imaging in the UV-Visible-Near Infrared Spectrum

This is the most common technique used with satellite and aerial sensors. Wavelengths (colors) within the range of the human eye are most often used but Ultraviolet (UV) wavelengths are useful for detecting fluorescence from petroleum compounds (oil, diesel, etc.) and near-IR wavelengths can be useful for correcting atmospheric interference from aerosols (e.g. smog and smoke).

The best detection capabilities are attained when several images in different wavelengths are acquired simultaneously. These "multispectral" data can be digitally processed to enhance features not readily visible in simple color photographs. For example, two such images can be ratioed, thus emphasizing the water features' differences in reflection of the two wavelengths. A multi-wavelength image set can also be analyzed with "multispectral classification algorithms" which separate different features or effluents based on the correlation relationships between the different color signals.

The depth to which the color sensors can penetrate depends on which wavelengths they see, their sensitivity and the general water clarity. In the San Diego region, green wavelengths tend to reach the deepest and, as elsewhere, UV and near-IR wavelengths penetrate the least. Generally, the satellites data used for this effort reveal patterns in the upper 15-40 feet.

2.2 Imaging in the Infrared Spectrum

Some satellite and aerial sensors take radiometric measurements of thermal energy radiated from the Earth's surface which can be used to calculate

temperature from the ground and the ocean. The differences in temperature can then be used to reveal important coastal and oceanographic patterns and features. Since infrared wavelengths are strongly absorbed by water, the images reveal temperature patterns only on the water's surface. Such images can help detect runoff plumes when their temperatures differ from the surrounding ocean water. Runoff from shoreline sources tends to be warmer than the ocean water, although the reverse can be true during the winter. Plumes from offshore outfalls can sometime also be detected with thermal imaging. Since the effluent contains mostly fresh water, it is less dense than the surrounding saltwater and tends to rise to the surface. If it makes it all the way, it is usually cooler than the surrounding sun-warmed surface water. If it is constrained by a strong thermocline and/or pycnocline ("vertical stratification"), it sometimes tends to displace some of the water above it in a doming effect. This displacement pattern is revealed in the thermal surface imagery. The Landsat 8 OLI/TIRS, Sentinel 3 SLSTR (Sea and Land Surface Temperature Radiometer), MODIS, VIIRS and AVHRR satellites/sensors all have thermal infrared channels as part of their sensor package.

2.3 Data Dissemination and Analysis

The satellite imaging data are made available to the funding agencies, the San Diego County Department of Health, and the EPA through a dedicated, password-protected web site. Although it is possible to process most of the used data in near-real-time, earlier in the project the funding agencies decided that the emphasis of this project is not on providing real-time monitoring support and the extra costs associated with the rapid data turn-around are not warranted. Most satellite data are thus processed and posted within 1-2 days after acquisition and the aerial sensor imagery

(which when used prior to 2010 required the most labor-intensive processing), within 2-5 days. OI has, however, in several cases, made some imagery available to the CDH and others in near-real time via email when observations were made that appeared to be highly significant for the management of beach closures or other sudden events. OI has developed an ArcGIS Server Web Map Service (WMS) with the intent of hosting oceanographic products produced daily by OI and automatically linked with the server as soon as available. Discussion follows on the use of the WMS to deliver data.

2.4 Present and Future Enhancements of the Remote Sensing Monitoring Project

In 2016, OI began to generate the ocean currents and other HYCOM-derived products in a Web Map Service (WMS) Representational State Transfer (REST) service format which is directly compatible with the ESRI WMS the City is working to implement. It was planned that all the OI-delivered data products, including all the satellite imagery would be delivered via OI's ArcGIS Server for easy ingestion into the City's ArcGIS online WMS by fall of 2017. To date, the City's WMS is not fully functional and ready to ingest data from OI's server, however OI has put in place all the delivery infrastructure to transition to this means of data and product delivery as soon as the City is ready. Discussions with the City's GIS personnel in late 2019 focused on ways to utilize the City's GIS infrastructure to ingest data from OI's WMS. Work to develop this method of disseminating all this project's data products continues in 2020. As part of this process, the historical imagery, data and reports will remain accessible via the existing web portal while OI and the City migrate all 2016-2020 data products to OI's ArcGIS Server. Following the completion of the migration of the 2016-2020 data to this system, OI will progressively work backwards in time to make all historical

data available to the City's ArcGIS online WMS.

Beginning in 2017, OI also began processing and posting imagery from the Sentinel-2A satellite. Sentinel-2A is a satellite operated by the European Space Agency (ESA) and is the spaceborne platform for the Multispectral Instrument (MSI). The Sentinel-2 Multispectral Instrument (MSI) samples 13 spectral bands: four bands at 10 meters, six bands at 20 meters and three bands at 60-meter spatial resolution. The green band focusing in the 560 nm wavelength is ideal for detecting turbidity plumes from the outfalls both at the surface and at depths down to 40 feet depending on ocean conditions. The revisit time of the Sentinel-2A satellite is approximately ten days. A second satellite carrying the MSI sensor, the Sentinel-2B, was launched into orbit by the ESA and provided the first set of data from the MSI sensor as of March 17, 2017. Beginning in 2018 data from Sentinel 2B became a regular addition to the satellite imagery products posted to the OI web portal. On average the Sentinel 2A and 2B imagery processed to highlight anomalous turbidity signals emanating from the Point Loma Ocean Outfall (PLOO), the South Bay Ocean Outfall (SBOO), as well as the discharge from the Tijuana River were posted to the OI web portal within 24-36 hours of satellite data acquisition. In some cases, if the data were available to OI earlier, the image products were delivered as quickly as 12 hours post acquisition. During 2019 the Sentinel 2A and 2B satellites provided the most temporarally comprehensive set of high-resolution satellite imagery. In total, 119 high resolution satellite images showing the offshore San Diego County region were acquired, processed, and delivered in 2019. This equates to a 45% increase in satellite data used to document the area when compared to 2018. Of the 119 total image sets, 85 were from Sentinel 2A or 2B data making up 71% of the high-resolution satellite data processed and

posted as part of the project and an increase of 35% over 2018. On average, this effectively increased the number of high-resolution satellite observations of the San Diego region to ten per month.

Appendix A includes the 2019 RapidEye, Sentinel and Landsat imagery on days which the SBOO plume was detected. There were eleven occurrences when either Sentinel 2A or 2B data were acquired within only a few minutes of either RapidEye, Landsat TM7 or Landsat 8 OLI/TIRS data providing a near time-coincident validation of features (or lack thereof) observed in the imagery. Figure 1 provides an example of the SBOO surface turbidity expression near-simultaneously observed by Sentinel 2B and RapidEye high resolution satellite sensors on 01/19/19. The surface turbidity plume extending south from the area directly above the SBOO is one of the largest/strongest observed in over fifteen years of imaging

the region. Additionally, significant discharge can be seen from the Tijuana River, Mission Bay and the San Diego River as well as San Diego Harbor. These excessive discharges are most likely due to continuous rainfall events between 01/12/19 and 01/17/19.

In October 2018, OI began using imagery from Sentinel-3A. Shortly thereafter, in December 2018 imagery from Sentinel-3B was incorporated as well. Just like Sentinel 2, Sentinel 3A and 3B are earth observation satellites developed by the European Space Agency for the Copernicus Program. Sentinel-3A was launched on February 16, 2016 and Sentinel-3B followed on April 25, 2018. The 3A and 3B satellites are identical and deliver products in near-real time. The satellites include 4 different remote sensing instruments. The Ocean and Land Color Instrument (OLCI) covers 21 spectral bands (400–1020 nm) with a swath width of 1270 km and a spatial



Figure 1. RapidEye (left) and Sentinel 2B (right) imagery of the San Diego region. The RapidEye data were acquired at 18:23 UTC (10:22 AM PST) and the Sentinel imagery at 18:37 UTC (10:37 AM PST) only 14 minutes apart. Note the very strong SBOO effluent signature visible in both datasets.

resolution of 300 m. The Sea and Land Surface Temperature Radiometer (SLSTR) covers 9 spectral bands (550-12 000 nm), using a dual-view scan with swath widths of 1420 km (nadir) and 750 km (backwards), at a spatial resolution of 500 m for visible and near-infrared, and 1 km for thermal infrared channels. The Sentinel 3 missions' main objectives are to measure sea surface topography along with the measurement of ocean/land surface temperature and ocean/land surface color. One of the satellites' main secondary missions is to monitor sea-water quality and marine pollution. The instrument on these satellites designed for these purposes is the OLCI. Ocean Imaging creates daily products dependent on cloud cover for the entire San Diego/Tijuana region using the OLCI instrument. Between the 3A and 3B satellites this results in better than daily coverage with 3A and 3B data occasionally both being available on the same day. True color, near infrared, and for select days Total Suspended Matter (TSM) products are posted bi-monthly along with the similar resolution MODIS products. The TSM product indicates the quantity in grams per cubic meter of suspended particles in water. TSM products are calculated from estimated inherent optical water properties such as pigment absorption and total scattering products at 443 nm. This empirical algorithm was created in order to evaluate the turbidity of water. Possible future products derived from the Sentinel 3 sensors include chlorophyll and sea surface temperature as well as cyanobacteria monitoring. Sentinel 3 carries the only satellite sensor package with the necessary spectral bands, spatial resolution, and coverage for near real-time detection of cyanobacteria. The results of these products may also be compared to the field sampling data in order to assess accuracy. Figure 2 shows a time series using Sentinel 3 data during a period of heavy river run off and strong SBOO surface turbidity expression between 01/19/19 and 01/23/19. The true color and TSM renderings of the data from 19th of January show, albeit as a lower

spatial resolution, the extensive turbidity plumes extending from the coast as well as the effluent plume emanating from the SBOO. However, they also show the relaxation of the coastal discharge and absence of a SBOO effluent signature by the 22nd of January. This offers a good example of how the Sentinel 3 data can fill in the temporal gaps to determine how long a wastewater surface plume persists over time.

As stated above, the RapidEye satellite data were discontinued as of late 2019 and replaced by data from the SPOT 6 and SPOT 7 satellites in January of 2020. The two SPOT satellites/sensors are identical in design and function. They both image in spectral bands similar to the RapidEye satellites at a ground sampling distance of 8.8 meters for the multispectral data. The dynamic range of these sensors is 12-bits per pixel.

SPOT6/7 spectral bands:

Panchromatic: 0.450-0.745µm

Blue: 0.450-0.520μm Green: 0.530-0.590μm Red: 0.625-0.695μm

Near-infrared: 0.760-0.890µm

OI uses the blue, green, red, and near-infrared bands for this project. Empirically we have found that the SPOT data have a high signal to noise ratio therefore produce a high-quality product in regard to detecting wastewater surface manifestations and delineating the river run-off plumes. Because of the ability of these sensors to image from off-nadir viewing angles it is also possible to obtain imagery close together in time. Figure 3 shows a set of SPOT images from 01/29/20 and 01/30/20 highlighting the ability (if necessary) to obtain this high-resolution imagery on successive days. Note the northward movement of the river plume and SBOO effluent on the 29th and the westward and southward movement of the plume and effluent waters on the 30th.

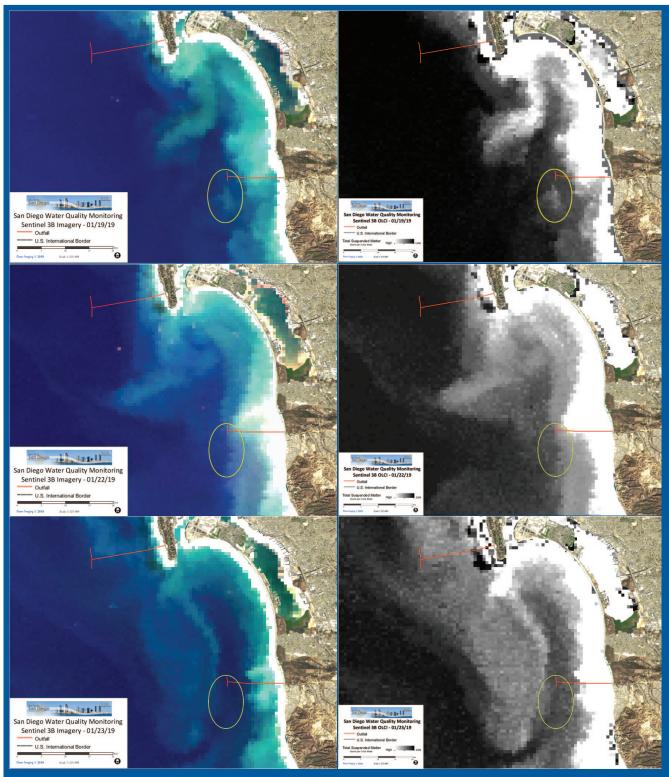


Figure 2. Sentinel 3 RGB (left) and TSM (right) images acquired on 01/19/19, 01/22/19 and 01/23/19. Note the SBOO effluent is visible on the surface on 01/19/19 but disappears by 01/22/19 through 01/23/19. Note southward movement of the turbidity plume coming off Point Loma on the 22nd and 23rd. This surface flow was corroborated by the HF (High Frequency) Radar-measured currents from the same day (not shown). The data from 01/19/19 was acquired on the same day shown in the higher resolution satellite imagery in Figure 1.

3. HIGHLIGHTS OF 2019 MONITORING

3.1 Atmospheric and Ocean Conditions

According to the San Diego International Airport station (formerly referred to as the Lindbergh Field station), in 2019 San Diego showed the highest cumulative annual precipitation total from the past eight years (15.52 inches). This is the 17th highest rainfall total recorded in San Diego since 1850 with the greatest total of 27.59 inches recorded in 1884. The average precipitation between 1850 and 2019 is 9.86 inches (NWS, San Diego). The Tijuana Estuary station reported a lower cumulative precipitation total in 2019 than San Diego station of 14.41 inches, however still higher than any of the seven years prior (Table 1). As has been noted in the previous reports, the monthly and annual precipitation amounts can differ at times between the two reporting stations.

The monthly precipitation totals recorded for 2019 followed normal patterns seasonally, but with a few months receiving unusually high rainfall totals. The winter months did experience the seasonally expected higher amounts of precipitation with June

through September following the typical dry season patterns. February, March and November, however, were atypical months compared to previous years, resulting in unusually high rainfall totals.

Figure 4 shows cumulative daily precipitation in the Tijuana River Estuary. The table to the side of the plot gives the dates for which there was measurable precipitation at that station. The periods of heavy and/or persistent rainfall in January, February, November, and December are reflected in the satellite imagery database. The coastal water quality changes are clearly visible in the Sentinel 2B and RapidEye imagery from 01/19/19 (Figure 1) following persistent precipitation from 01/12/19 through 01/17/19. The discharge from the Tijuana River was abnormally strong throughout the month of February as a result of the persistent and at times heavy rainfall in the region (1.11 inches recorded at the Tijuana Estuary station on 02/02/19). Figure 5 shows a satellite image time series during the month of February highlighting several days during which the Tijuana River plume reached beyond its normal offshore extent (as defined by Svejkovsky, et.al, 2010 and in the 2015 Five Year Summary Report). There were



Figure 3. SPOT imagery of the SBOO region on 01/29/20 (left) and 01/30/20 (right). Both show an SBOO effluent surface signature as well as coastal runoff plumes, however the switch in direction of movement of these features changes dramatically in the 24 hour period between the two satellite data acquisitions.

no detectable surface manifestations of the SBOO turbidity plume during the month of February.

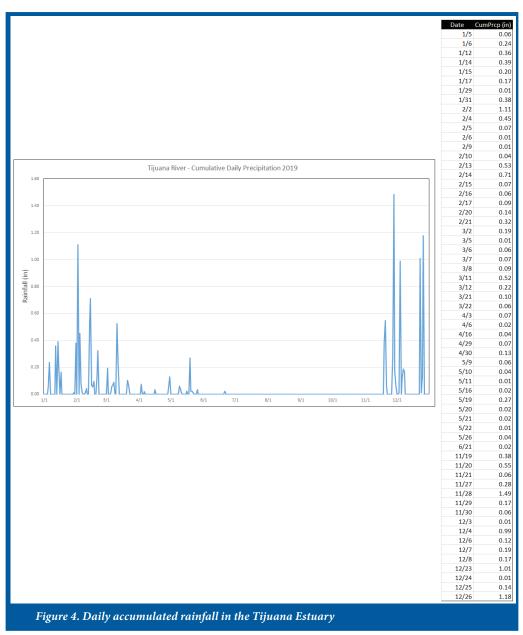
The first three weeks of March showed eight days of detectable precipitation from 03/05/19 through 03/22/19 resulting in higher than normal Tijuana River discharge continuing through the end of the month. The most notable river discharge event in

March was visible in the Sentinel imagery acquired on 03/22/19 following 0.52 inches of rainfall measured the day prior. Aside from a rainfall event on 05/19/19, the period of May through the first half of November was lacking in any significant precipitation. From 11/19/19 through the end of the year precipitation was exceptionally high when compared to previous years. Figure 6 contains a Sentinel image

Table 1. San	Table 1. San Diego and Tijuana Estuary precipitation totals 2019									
San Diego Inte	San Diego Internationl Airport Cumulative Monthly Precipitation in Inches									
	2012	2013	2014	2015	2016	2017	2018	2019		
January	0.40	0.70	0.01	0.42	3.21	2.99	1.77	2.42		
February	1.19	0.63	1.00	0.28	0.05	1.58	0.35	4.04		
March	0.97	1.22	1.28	0.93	0.76	0.08	0.65	1.23		
April	0.88	0.01	0.54	0.02	0.55	0.01	0.02	0.10		
May	0.02	0.26		2.39	0.44	0.87	0.09	0.86		
June				0.04		0.02		0.01		
July		0.05		1.71						
August			0.08	0.01			0.02			
September				1.24	0.32	0.06		0.11		
October	0.70	0.25		0.43	0.07		0.57			
November	0.28	1.48	0.37	1.54	0.61	0.02	0.69	2.72		
December	2.19	0.46	4.50	0.88	4.22		0.83	4.03		
Annual Total	6.63	5.06	7.78	9.89	10.23	5.63	4.99	15.52		
Tijuana Estua	ry Cumul	ative Mon	thly Preci	pitation ir	Inches		_			
	2012	2013	2014	2015	2016	2017	2018	2019		
January	0.70	0.05	0.08	0.32	2.40	3.61	0.82	1.80		
February	0.86		1.35	0.13	0.02	4.06	0.47	3.62		
March	1.21	1.43	0.55	1.01	1.28	0.04	1.17	1.33		
April	0.82	0.11	0.35	0.07	1.91	0.01	0.10	0.33		
May		0.36		1.13	0.97	1.07	0.08	0.50		
June			0.12					0.02		
July		0.01	0.33	0.39		0.01	0.01			
August			0.04			0.02				
September	0.02	0.01		0.48	0.49	0.03				
October	0.50	0.41		0.21			0.13			
November		0.25	0.29	0.61	0.34	0.06	0.82	2.99		
December	0.04	0.50	3.09	0.61	4.32	0.09	3.16	3.82		
Annual Total	4.15	3.13	6.20	4.94	11.73	8.99	6.76	14.41		

from 10/21/19 which, even though October is considered to be fall, is representative of the clear water conditions during the summer. The typically summer conditions extended into the first part of November most probably because there was almost no rainfall recorded from June through October (only 0.11 inches recorded at the San Diego airport station during these months). Aside from a mild chlorophyll bloom off the coast, little coastal turbidity exists in the region. It is paired with a Sentinel image acquired

on 11/22/19 following significant rainfall events from 11/19/19 through 11/21/19. This image exhibits a large Tijuana River plume moving north into San Diego waters. HF Radar currents from the same day confirm what is seen in the satellite imagery (Figure 8A). As measured by San Diego International Airport station, the month of November experienced the 11th highest rainfall amount measured between 1850 and 2019. The month of December resulted in the 18th highest total since 1850 (NWS, San Diego).



The first and last weeks of December experienced heavy and persistent rainfall resulting in extensive river runoff for much of that month. A December Sentinel 2A image highlighting a particularly large Tijuana River plume extending up past the west side of Point Loma is provided in Figure 8B.

Similar patterns can be seen in Figure 7 which plots the daily San Diego River flow rates in cubic feet per second measured by the United States Geological Survey (USGS) Fashion Valley gauge. Monthly precipitation totals at the San Diego International Airport station are displayed to the right of the plot. In general, the 2019 the river flow rates matched what would be expected given seasonal rainfall patterns, however there are unusual peaks in February and late May which correspond to the extended period of precipitation in February and a heavy rain event on 05/19/19. The flow rates did peak in late November and December as would be expected given the heavy rainfall event during that time.

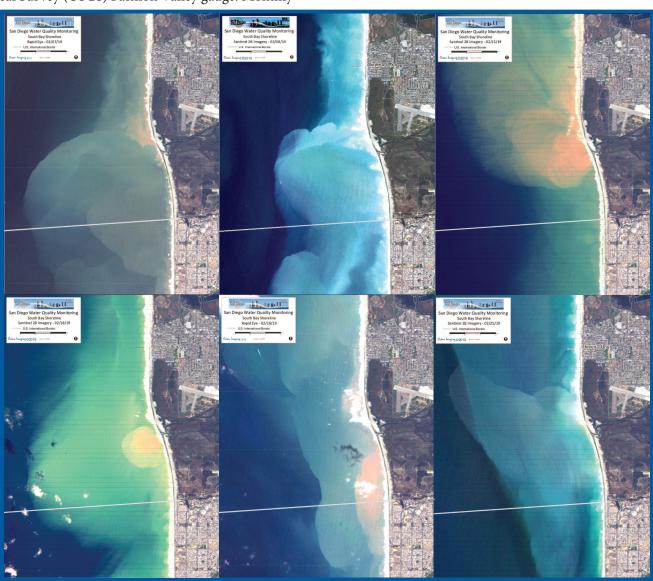


Figure 5. A high-resolution satellite image time series of the Tijuana River region highlighting several days in February during which the Tijuana River plume reached beyond its normal offshore extent.

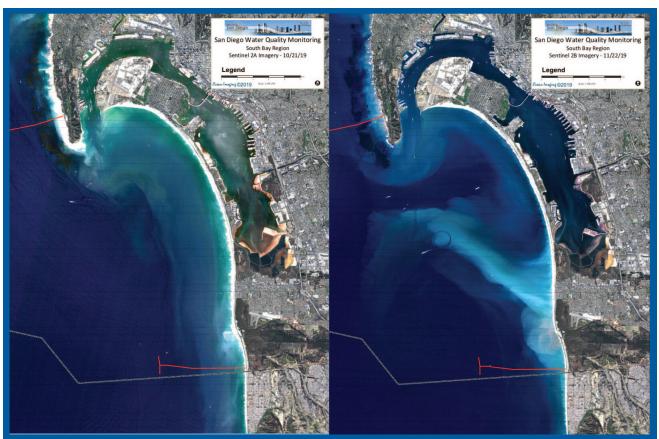
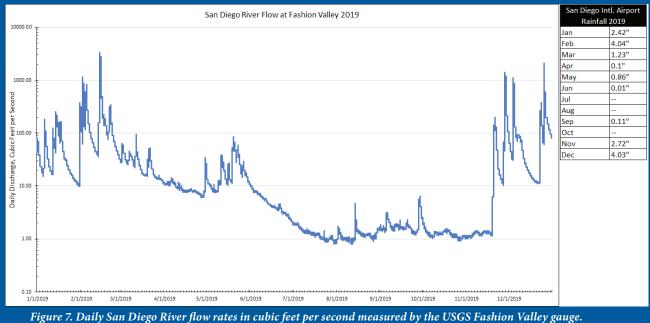


Figure 6. Sentinel image from 10/21/19 (left) illustrating the relatively clear-water conditions during the summer to fall months. Aside from a mild chlorophyll bloom off the coast, little coastal turbidity exists in the region between June and October. It is paired with a Sentinel image acquired on 11/22/19 (right) following significant rainfall events from 11/19/19 through 11/21/19. A large Tijuana River plume is observed moving north into San Diego waters.



In 2019 the county of San Diego issued 166 posted shoreline and/or rain advisories and 32 beach/shoreline closures. This is twice as many closures when compared to the prior year. The longest contiguous 2019 closure lasting 164 days between January 1 and June 14 was in Border Field State Park along the south end of the Tijuana Slough Shoreline. This closure was an extension from 2018 and so in reality lasted 197 days. As is typical for the region, almost all the closures were in the area between the Tijuana River mouth and Avenida Del Sol at the south end of North Island. With the exception of those during the June through September summer months, almost all of the closures can be attributed to a rain event prior to and/or during the closure period. All except two were associated with Tijuana River discharge. One closure 04/12/19 at Wind and Sea Beach was the result of a sewage spill in that area (Table 2) and cannot be directly correlated to any rain events.

The satellite imagery available on the web portal on or around the closure dates and rainfall events visually correlate with the closure data. Imagery during those time periods show high turbidity and suspended solid levels along the coastline in the closed region as well as persistent, higher than normal TJR runoff, sometimes being carried north by the ocean currents. Figures 8A and 8B provide visual examples of the Tijuana River plume extending north corresponding with shoreline closures during the same time period.

Although discharge from the San Diego River does not cause the same level of beach contamination issues as the Tijuana River discharge, the runoff from the two rivers, Mission Bay and coastal lagoons did affect nearshore water clarity on several days throughout the year in 2019, directly as a source of suspended sediment and indirectly as a source of high nutrient level encouraging localized plankton blooms. Figure 9 from 02/15/19 provides a dramatic example of this situation.

The coast of San Diego County, as well as a large percentage of the California Bight, experienced moderate to high chlorophyll levels for most of the year indictive of frequent and persistent phytoplankton blooms throughout 2019. Figure 10 provides representative MODIS-derived chlorophyll imagery for each month of the year illustrating that there were few periods during which the ocean waters offshore of San Diego experienced low chlorophyll. Due to imperfections in the NASA and NOAA algorithms used to measure chlorophyll_a using satellite data, however, coastal turbidity can often be misrepresented as high chlorophyll levels. It can therefore be assumed that a significant portion of chlorophyll shown along the coast in the MODIS, VIIRS and Sentinel 3 imagery for the months of January, February, March, November and December is actually turbidity created by heavy rainfall events occurring during those months. All the other phytoplankton bloom events were most likely the result of localized and/or regional coastal upwelling and the influence of the California Current bringing cool, nutrientrich water into the region. Only for short periods of time in March and May did the San Diego coastal region show relatively low levels of chlorophyll/phytoplankton or turbidity as measured by satellite.

In most cases the City of San Diego CTD data corroborated the chlorophyll levels seen in the satellite data. Some of the highest chlorophyll levels recorded via CTD (10.0-59.0 μ g/L) occurred between May and September. These months, especially the end of May, August and September showed consistently high chlorophyll in the satellite data not only in the San Diego area, but over the entire Southern California region. One example is the period of 05/24/19-05/29 during which high chlorophyll levels were observed in the imagery and notably high readings (as high as 25.3 μ g/L) were recorded in the CTD data taken on 05/29/19. Likewise, some of the lowest chlorophyll levels (0.01–1.5 μ g/L) docu-

Table 2. 2019 County of San Diego shoreline closures and advisories (courtesy of the County of San Diego Department of Environmental Health).											
Station Description	Beach Name	Station Name	Туре	Cause	Source	Start Date	EndDate	Closest Rain Event	Closure length	Time from Rain Event	Satellite
Border Fence N side	Border Field State Park	IB-010	Closure	Tijuana River	Rain	1/1/2019	6/14/2019	12/31/2018	164	1	12/27/2019
All_SanDiego_County_Beaches	All_SanDiego_County		Rain Advisory			1/6/2019	1/9/2019	1/5/2019	3	1	1/4/2019
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River	Unknown	1/9/2019	1/12/2019	1/6/2019	3	3	1/9/2019
All_SanDiego_County_Beaches	All_SanDiego_County		Rain Advisory			1/12/2019	1/21/2019	1/12/2019	9	0	1/9/2019
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River	Unknown	1/15/2019	1/22/2019	1/15/2019	7	0	1/19/2019
Avd. del Sol	Coronado City beaches	IB-080	Closure	Tijuana River	Unknown	1/16/2019	1/21/2019	1/15/2019	5	- 1	1/19/2019
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River	Unknown	1/16/2019	1/21/2019	1/15/2019	5	1	1/19/2019
All_SanDiego_County_Beaches	All_SanDiego_County		Rain Advisory			1/31/2019	2/8/2019	1/31/2019	8	0	1/26/2019
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River	Unknown	2/1/2019	2/10/2019	1/31/2019	9	1	1/26/2019
Avd. del Sol	Coronado City beaches	IB-080	Closure	Tijuana River	Unknown	2/1/2019	2/8/2019	1/31/2019	7	I	1/26/2019
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River	Unknown	2/1/2019	2/8/2019	1/31/2019	7	I	1/26/2019
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River	Unknown	2/14/2019	2/21/2019	2/14/2019	7	0	2/15/2019
Avd. del Sol	Coronado City beaches	IB-080	Closure	Tijuana River	Unknown	2/14/2019	2/20/2019	2/14/2019	6	0	2/15/2019
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River	Unknown	2/14/2019	2/20/2019	2/14/2019	6	0	2/15/2019
All_SanDiego_County_Beaches	All_SanDiego_County		Rain Advisory			2/14/2019	2/25/2019	2/14/2019	II	0	2/15/2019
All_SanDiego_County_Beaches	All_SanDiego_County		Rain Advisory			3/2/2019	3/11/2019	3/2/2019	9	0	2/25/2019
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River	Unknown	3/3/2019	3/5/2019	3/2/2019	2	- 1	3/5/2019
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River	Unknown	3/6/2019	3/12/2019	3/6/2019	6	0	3/5/2019
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River	Unknown	3/6/2019	3/12/2019	3/6/2019	6	0	3/5/2019
All_SanDiego_County_Beaches	All_SanDiego_County		Rain Advisory	,		3/12/2019	3/15/2019	3/12/2019	3	0	3/12/2019
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River	Unknown	3/19/2019	3/23/2019	3/12/2019	4	7	3/17/2019
Playa Del Norte	WindanSea Beach	EH-280	Closure	Sewage Spill	Sewer Line	4/12/2019	4/14/2019	4/6/2019	2	6	
All_SanDiego_County_Beaches	All_SanDiego_County		Rain Advisory	218-1		4/29/2019	5/2/2019	4/29/2019	3	0	4/17/2019
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River	Unknown	5/2/2019	5/5/2019	4/30/2019	3	2	5/1/2019
All_SanDiego_County_Beaches	All_SanDiego_County		Rain Advisory			5/16/2019	5/19/2019	5/16/2019	3	0	5/14/2019
All_SanDiego_County_Beaches	All_SanDiego_County		Rain Advisory			5/20/2019	5/23/2019	5/19/2019	3	ı	5/23/2019
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River	Unknown	5/26/2019	5/28/2019	5/26/2019	2	0	5/24/2019
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River	Unknown	5/30/2019	6/2/2019	5/26/2019	3	4	5/29/2019
Border Fence N side	Border Field State Park	IB-010	Closure	Tijuana River	Unknown	6/27/2019	7/12/2019	6/21/2019	15	6	6/30/2019
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River	Unknown	7/9/2019	7/10/2019	6/21/2019	1	18	7/8/2019
Border Fence N side	Border Field State Park	IB-010	Closure	Other	Sewage/ Grease	7/27/2019	8/2/2019	6/21/2019	6	36	7/26/2019
Border Fence N side	Border Field State Park	IB-010	Closure	Tijuana River	Unknown	9/6/2019	9/24/2019	6/21/2019	18	11	9/3/2019
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River	Unknown	9/7/2019	9/14/2019	6/21/2019	7	78	9/8/2019
All_SanDiego_County_Beaches	All_SanDiego_County		Rain Advisory	,		11/20/2019	11/24/2019	11/20/2019	4	0	11/17/2019
Border Fence N side	Border Field State Park	IB-010	Closure	Tijuana River	Sewage/ Grease	11/21/2019	12/31/2019	11/21/2019	40	0	11/22/2019
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River	Coastal outlets	11/21/2019	12/11/2019	11/21/2019	20	0	11/22/2019
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River	Sewage/ Grease	11/22/2019	11/26/2019	11/21/2019	4	Ι	11/22/2019
All_SanDiego_County_Beaches	All_SanDiego_County		Rain Advisory			11/27/2019	12/3/2019	11/27/2019	6	0	11/23/2019
All_SanDiego_County_Beaches	All_SanDiego_County		Rain Advisory			12/4/2019	12/11/2019	12/4/2019	7	0	12/3/2019
Avd. del Sol	Coronado City beaches	IB-080	Closure	Tijuana River	Sewage/ Grease	12/5/2019	12/11/2019	12/4/2019	6	I	12/5/2019
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River	Sewage/ Grease	12/5/2019	12/11/2019	12/4/2019	6	I	12/5/2019
All_SanDiego_County_Beaches	All_SanDiego_County		Rain Advisory			12/23/2019	12/29/2019	12/23/2019	6	0	12/25/2019
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River	Sewage/ Grease	12/24/2019	12/31/2019	12/24/2019	7	0	12/27/2019
Avd. del Sol	Coronado City beaches	IB-080	Closure	Tijuana River	Sewage/ Grease	12/24/2019	12/29/2019	12/24/2019	5	0	12/27/2019
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River	Sewage/ Grease	12/24/2019	12/31/2019	12/24/2019	7	0	12/27/2019

mented in the CTD data occurred during the early weeks of May which was observed in the MODIS and VIIRS San Diego region imagery (Figure 11).

In the beginning days of August, CTD measurements off San Diego revealed some of the highest (> 10.0 µg/L) as well as lowest chlorophyll levels (< $1.0 \mu g/L$) between 08/05/19 and 08/08/19. The satellite imagery (while quite cloudy during this period), exhibited consistently strong chlorophyll blooms on these days, but with distinct defining boundaries. Part of the reason for the difference between the CTD and satellite data could be explained by the location and depth of the CTD sampling and smallscale differences in well-defined chlorophyll patterns. Some of the stations were outside of the core of the phytoplankton bloom with sharp gradients over short horizontal distances. Significant differences in CTD readings were measured from station to station indicating strong, but localized, patchy blooms. It also appears that the chlorophyll maximum was between roughly three and twenty meters deep, resulting in low chlorophyll measurements at the surface and high readings at depth. This would coincide with thermal stratification that is common during these months and explain the lack of precise correlation to the imagery during that time. Satellite sensors typically can only record values down to where light is no longer reflected back to the surface, the 1% Photosyntheically Available Radiation depth (0.1 PAR) (Giles-Guzmán, 2000). The depth at which satellite sensors can effectively measure chlorophyll thus varies depending on the classification (Case 1 vs. Case 2 waters, Morel and Prieur, 1977) and turbidity level in the water column being imaged. As noted above, generally, the satellites data used for this effort reveal patterns in the upper 15-40 feet, perhaps deeper if the turbidity levels are low. Figure 12 shows a high-resolution Sentinel 2 image next to a lower resolution MODIS RGB image showing a small, let well-defined plankton bloom with the CTD station plotted over the imagery. See Table 3 listing the CTD-derived chlorophyll measurements at three different depths for the stations in Figure 12.

3.2 The South Bay Ocean Outfall Region.

The South Bay Ocean Outfall (SBOO) wastewater plume generally remains well below the surface between approximately late March and November due to vertical stratification of the water column. During that period, it usually cannot be detected with multispectral aerial and satellite imagery which penetrate the upper 7 to 15 meters (depending on water clarity). The plume also cannot be detected with thermal IR imaging which does not penetrate below the surface. Seasonal breakdown of the vertical stratification results in the plume's rise closer to the surface or to actually reach the surface between approximately late November and late March, when it can often be detected with aerial and satellite imaging. For the most part this concept held true in 2019 as the SBOO plume was observed reaching the surface only once between late March and mid-November (faint signature on 04/01/19 – Appendix A).

The SBOO treatment plant switched from advanced primary to secondary treatment in January 2011. This change resulted, among other factors, in the reduction of total suspended solids (TSS) concentrations from an average of 60 mg/l for several years prior to the change, to 15 mg/l. Prior to 2011, a distinct effluent signature was regularly detected in multispectral imagery as per the seasonal fluctuation described above. Since then, the effluent signature continues to be observed with multispectral color and thermal imagery during months with weak vertical stratification, however, more intermittently. On occasion the signature is distinctly discernable in thermal images (indicating it has fully reached the ocean surface), but undetectable in the color imagery. We believe this is due to the reduction in TSS concentrations.

The effluent plume's reflectance signature in the multispectral visible and near-IR imagery is domi-

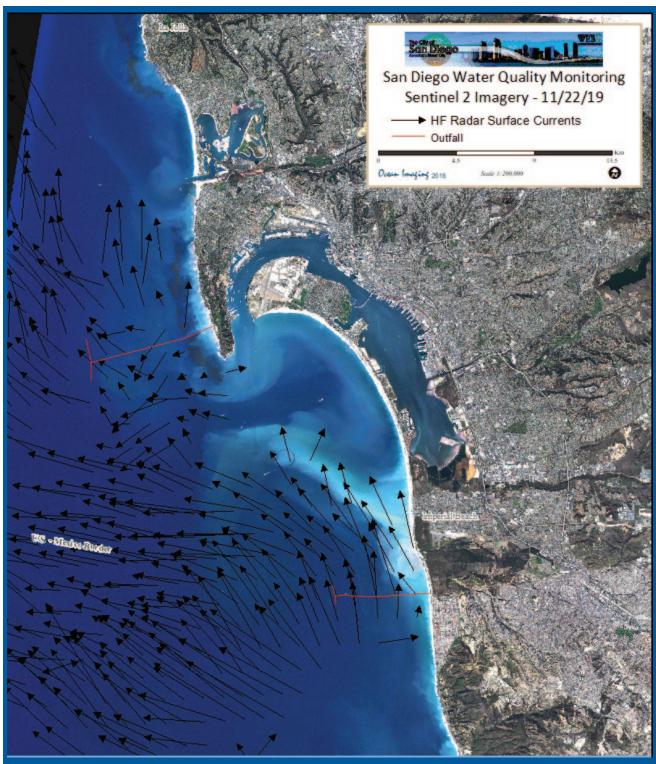


Figure 8A. Sentinel 2 image acquired at 18:26 UTC on 11/22/19 with the HF Radar-generated surface currents from 16:00 UTC from the same day overlaid on the imagery. Both the imagery and the currents illustrate the movement of TJR discharge water up into the San Diego region forcing the closure of shoreline areas as far north as Silver Strand State Beach. The accumulated rainfall as measured by the Tijuana Estuary station from 11/19/19-11/21/19 totaled to 0.99 inches.

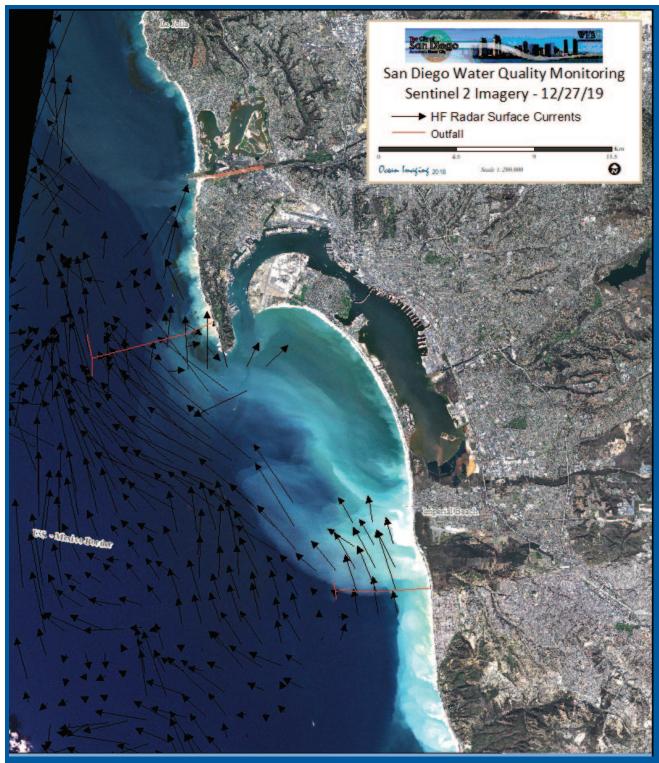


Figure 8B. Sentinel 2 image acquired at 18:27 UTC on 12/27/19 with the HF Radar-generated surface currents from 16:00 UTC from the same day overlaid on the imagery. Both the imagery and the currents illustrate the movement of TJR discharge water into the San Diego region forcing the closure of shoreline areas as far north as the Coronado beaches. Note that in this situation, the turbidity plume reaches as far north as Point Loma. The accumulated rainfall as measured by the Tijuana Estuary station from 12/23/19-12/26/19 totaled 2.34 inches.

nated by reflectance spectrum characteristics of its suspended sediment. Hence a reduction in the sediment concentration can be expected to affect the detectability of the plume. However, analysis of the size and intensity of the plume patterns relative to the TSS reductions does not show a direct correlation. In fact, some of the largest effluent signatures have been imaged after the secondary treatment switch, such as on 4 January 2012, when the TSS load was approximately 50% of concentrations in the early years. In that instance the effluent plume signature was identifiable up to more than 4km away from SBOO wye. In 2019 there were two occasions, on 01/19/19 and 12/20/19, when the plume signature extended at least 4km from the wye - both in the southerly direction. Other effluent signatures imaged during 2013 and 2014 when TSS loads were approximately 16 mg/L show that these are sufficient for adequate separation of the effluent from surrounding waters if the plume remains concentrated.

There were twenty instances for which the SBOO effluent plume was observed in 2019 out of the 119 high resolution satellite scenes acquired and processed. Of these twenty, three were instances of the plume observed by different satellites on the same day. This equates to seventeen days on which the plume was visible in the imagery. This is more often than the three years prior, however there were also more highresolution satellite scenes acquired in 2019 to detect the anomalies. In 2016 the SBOO effluent plume was observed 32.5% of the time (13 detections out of 40 high-resolution satellite images); in 2017 the plume was observed 10.9% of the time (6 detections in 55 images); in 2018 the plume was observed 18.3% of the time (15 detections in 82 images and in 2019 the plume was observed 14.7% of the time (17 detections in 116 satellite images - accounting for the duplicates). It should be noted that in six of the seventeen detections the plumes were relatively small and faint

and only detectable by maximizing the enhancement of the image data around the outfall region.

As have been the case in previous years, there were a few occurrences on 03/17/19 and 04/01/19 when the SBOO effluent plume appears in the imagery as a patch of clearer water breaking the more turbid water on the surface. As has been discussed in prior reports, the clear effluent signal in the imagery was most likely due to the contrast between the higher turbidity coastal surface waters and the 'normal' level of turbidity of the effluent water breaking the surface. It is also possible that the effluent plume became somewhat diluted on its way to the surface if weak vertical stratification did exist, thus slowing down its rise in the water column. CTD readings were not taken near this date to validate what was seen in the satellite date. This occurrence can be seen in the Sentinel imagery found in Appendix A. The period between 11/22/19 and 12/27/19 exhibited the highest number of 2019 SBOO effluent plume observations in the satellite data. As is typically the case, the relatively frequent effluent surfacing events that occurred during this time period were most probably the result of two primary factors: the lack of strong vertical stratification during the winter months and perhaps relatively weak subsurface currents over the SBOO which allowed the undispersed effluent to reach the surface.

In 2019 the shoreline area of the SBOO/Tijuana River outflow region experienced 101 days on which the field sampling showed elevated bacteria levels as defined by the California Ocean Plan (totals >10,000 CFU/100mL; fecal coliforms >400 CFU/100 mL; Enterococcus >104 CFU/100 mL or the FT ratio criterion is met: totals > 1,000 when fecals:totals > 0.1). The offshore SBOO region, which includes the stations over the SBOO wye, experienced only 3 days of elevated bacteria levels at depths of six meters or

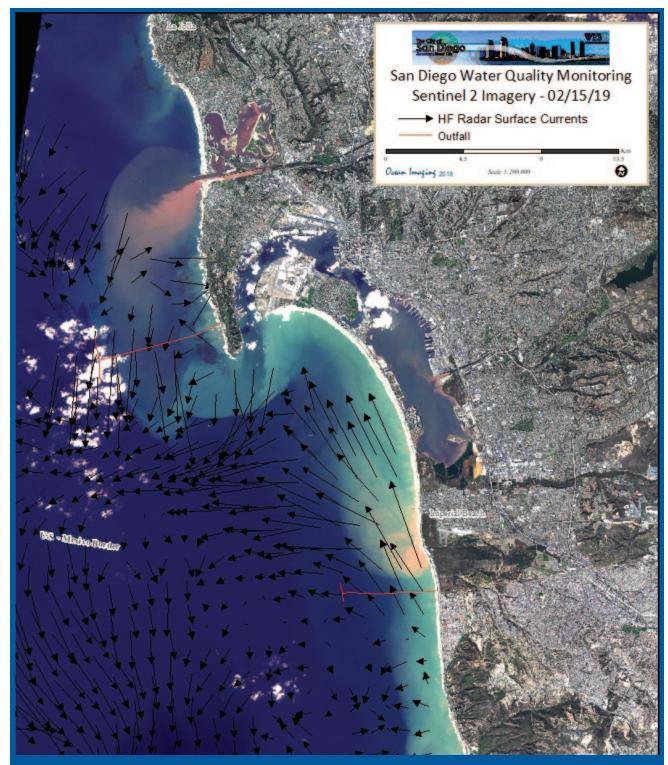
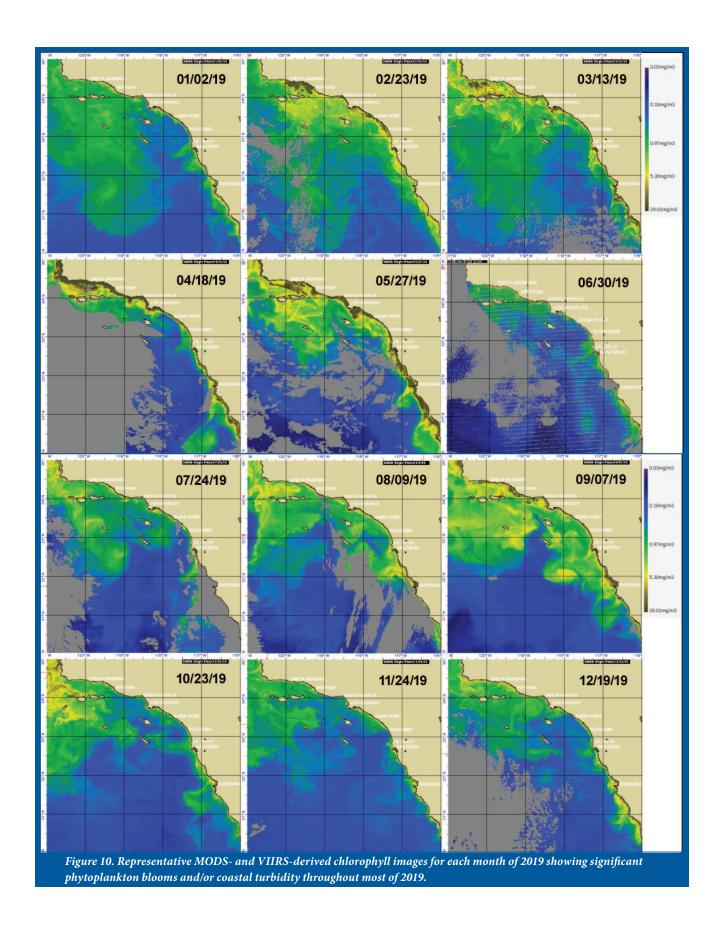


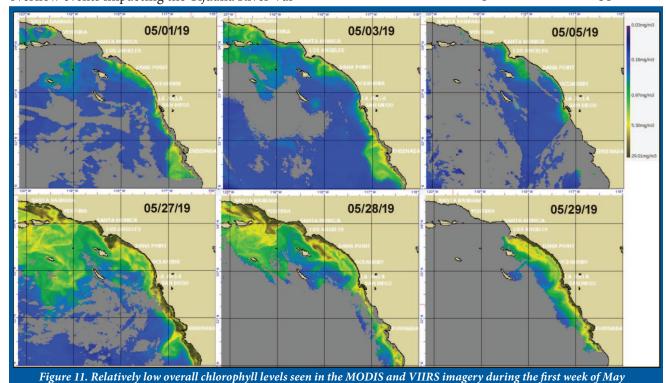
Figure 9. Sentinel 2 image acquired at 18:24 UTC on 02/15/19 with the HF Radar-generated surface currents from 16:00 UTC from the same day overlaid on the imagery. An unusually turbid plume is observed emanating from the San Diego River and curling down to the Point Loma kelp beds. The accumulated rainfall as measured by the San Diego International Airport station totaled 1.06 inches between 02/14/19-02/15/19.



shallower and the kelp region experienced 23 days on which the bacteria levels at depths of six meters or shallower were considered elevated. In 2018 the number of elevated bacteria days in the shoreline region numbered 17 days and only 2 days between the offshore and kelp regions combined. The number of sample day for all three SBOO areas (either along the shoreline or at six meters or shallower) totaled 164 in 2019 and 157 in 2018. In 2019 for the three sampling regions combined, 71.9% of the sampling days resulted in elevated bacteria levels at one station or more. This compares to a 12.1% elevated bacteria rate for the three areas in 2018. It should be noted, however, that there were far fewer sampling days for the shoreline region in 2018 (36) compared to 2019 (124) and the largest 2018 to 2019 increase in elevated bacteria days occurred in the shoreline region. In addition, 2019 experienced a high number and volume of sewage spills in the TJR/SBOO region with several sanitary sewer overflow events impacting the Tijuana River Val-

ley during both 2018 and 2019 (IBWC 2018-2019).

Strong TJR runoff seen in the satellite imagery and linked to time periods which experienced heavy and/ or persistent rainfall is the most plausible cause for the majority of the elevated bacteria samples. This is apparent in the imagery showing strong turbidity plumes along the coast, but not extending far enough offshore to affect the SBOOOffshore stations. In some cases, the TJR turbidity plume moved either north or south as opposed to directly west or southwest into the area of the SBOO wye. Figure 13 provides an example of the magnitude and geographical extent of the TJR discharge plume and its effect on the measured bacteria levels. The strong TJR discharge induced by heavy rains between 02/10/19-02/15/19 moved north driven by the prevailing currents as opposed to far offshore (see Figure 9). Therefore, we see high bacteria levels along the shoreline and much lower readings offshore. One week prior, however, the ocean surface flow pattern was in the opposite



and high Chlorophyll levels evident in the imagery during the last week of May.

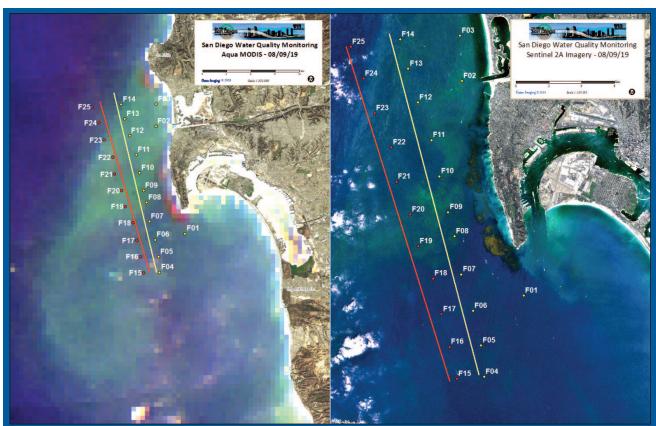


Figure 12. 250-meter MODIS RGB satellite image (left) and 10-meter Sentinel 2A image (right) of a plankton bloom off Point Loma on 08/09/19. Sampling stations for the CTD data taken on 08/08/19 and 08/09/19 are overlaid corresponding to the Chl_a data listed in Table 3 below.

Table 3. CTD-derived chlorophyll measurements recorded at depths of 1, 10 and 30 meters on 08/08/19 and 08/09/19 at the stations shown in Figure 12.

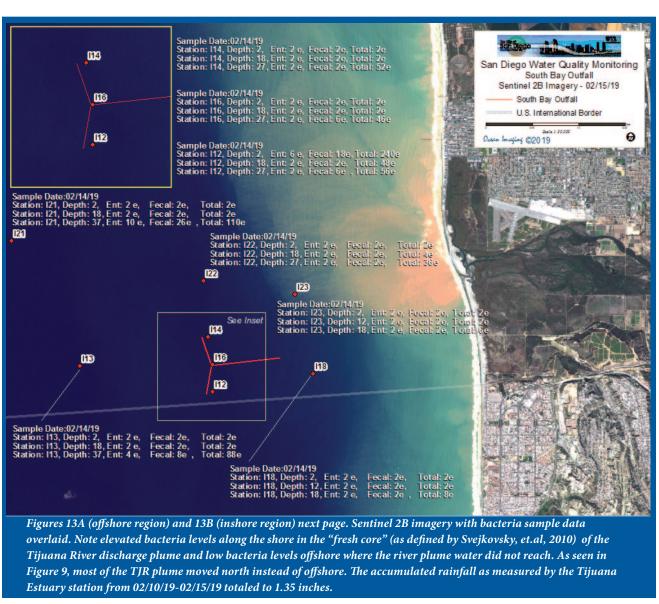
Chlorophyll Sampling 8/8/19 (Chl_a µg/L)			Ch	lorophyll Sampling	<mark>8/9/19 (Chl_a</mark> µg	/L)	
Station ID	I Meter Depth	10 Meter Depth	30 Meter Depth	Station ID	I Meter Depth	10 Meter Depth	30 Meter Depth
FOI	0.62	4.48	N/A	FIS	0.82	2.28	0.97
F02	4.08	7.59	N/A	FI6	1.05	2.73	0.95
F03	3.2	6.81	N/A	FI7	0.93	3	0.9
F04	0.86	1.71	0.66	FI8	0.89	2.78	1.1
F05	0.83	3.09	0.84	FI9	0.84	6.86	1.33
F06	0.81	2.97	1.23	F20	1.44	5.44	1.24
F07	0.88	2.39	1.99	F2I	1.43	4.46	0.64
F08	0.9	4.25	1.48	F22	1.52	3.46	0.78
F09	0.8	2.99	0.95	F23	1.31	4.92	0.91
FIO	2.17	11.14	1.14	F24	1.41	4.5	0.81
FII	3.31	4.9	0.89	F25	1.12	1.58	1.32
FI2	1.95	4.49	1.14				
FI3	2.31	4.91	0.6				
FI4	3.06	5.77	0.58				

direction. The extensive TJR plume resulting from heavy rains in the region from 02/02/19 through 02/06/19 is exhibited in Figures 14A and 14B.

RapidEye imagery acquired on 02/07/19 shows the plume water moving to the southwest and not reaching the offshore or northern sampling stations. This imagery corroborates the elevated bacteria readings to the south and southwest of the river mouth and normal to low measurements to the west and north.

The best water quality and clarity in the South Bay region in 2019 was observed from June through August. There was only one day when elevated

bacteria levels were recorded at the SBOO Offshore and SBOO Kelp stations, and six days recorded at the SBOO Shoreline stations during this time period. Five of the six recorded elevated bacteria measurements at the shore stations were at the far south station S0. The other was recorded on 06/04/19 at the shoreline S9 south of Coronado. The summer was seasonally dry with only on rain event recorded in June. No SBOO plume signatures were seen in the satellite imagery during this time. The bacteria sampling data from 08/19/19 overlaid on top of the Sentinel 2A satellite data illustrate the good water quality conditions during this time period



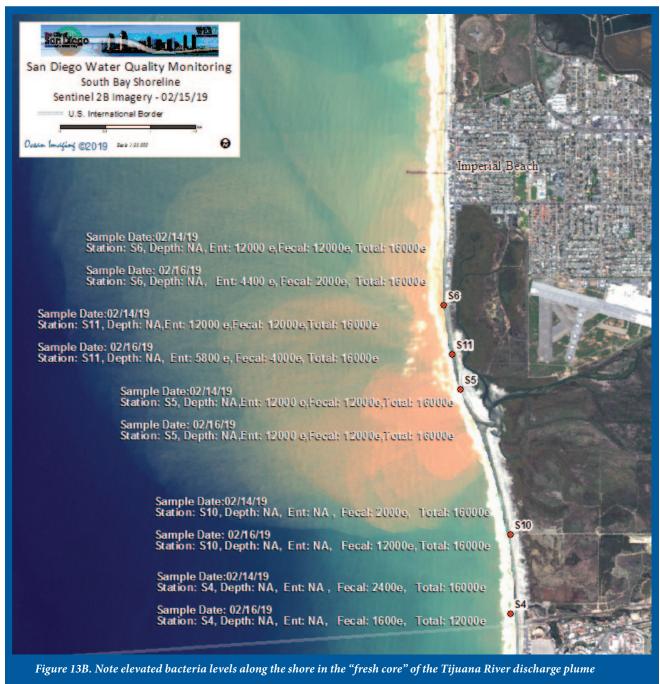
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(Figure 15). On the same day, however chlorophyll measurements acquired from the City's CTD sampling were relatively high in the area indicating the presence of phytoplankton blooms.

3.3. The Point Loma Outfall Region

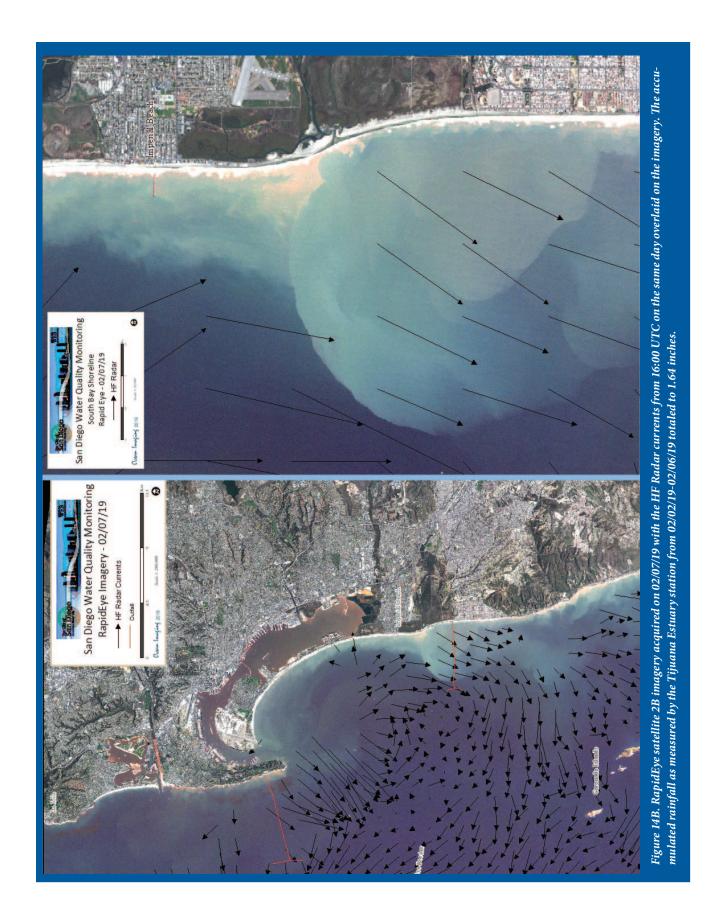
After its seaward extension in 1993, the Point Loma

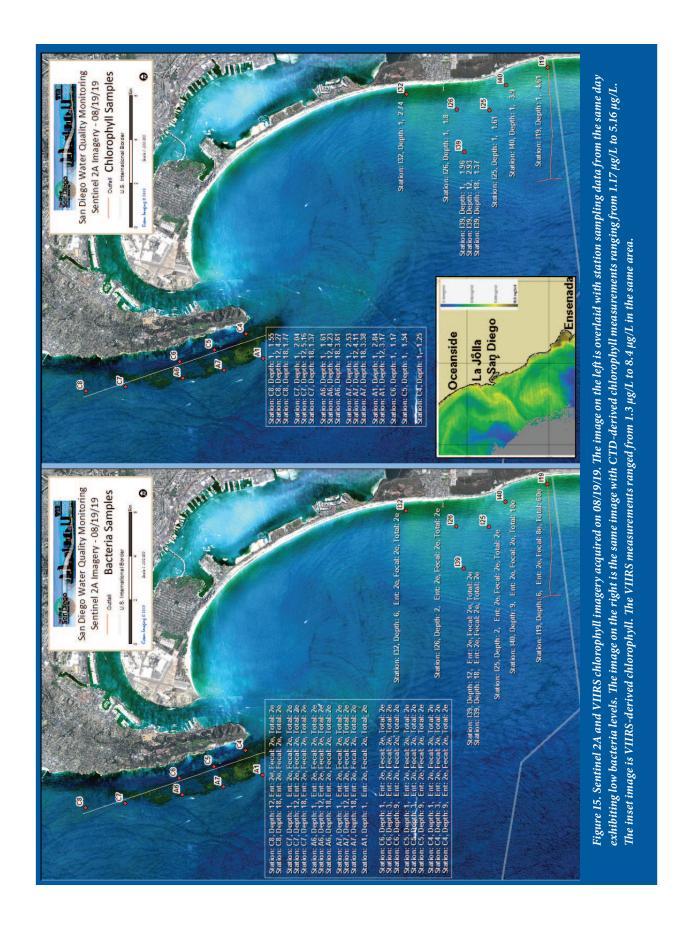
Outfall (PLOO) is one of the deepest and longest wastewater outfalls in the world, discharging at the depth of 320 feet, 4.5 miles offshore. The outfall's plume is generally not observed directly with multispectral color or thermal imagery. It appears to not reach the surface waters, even during the winter months when the water column's vertical stratifica-





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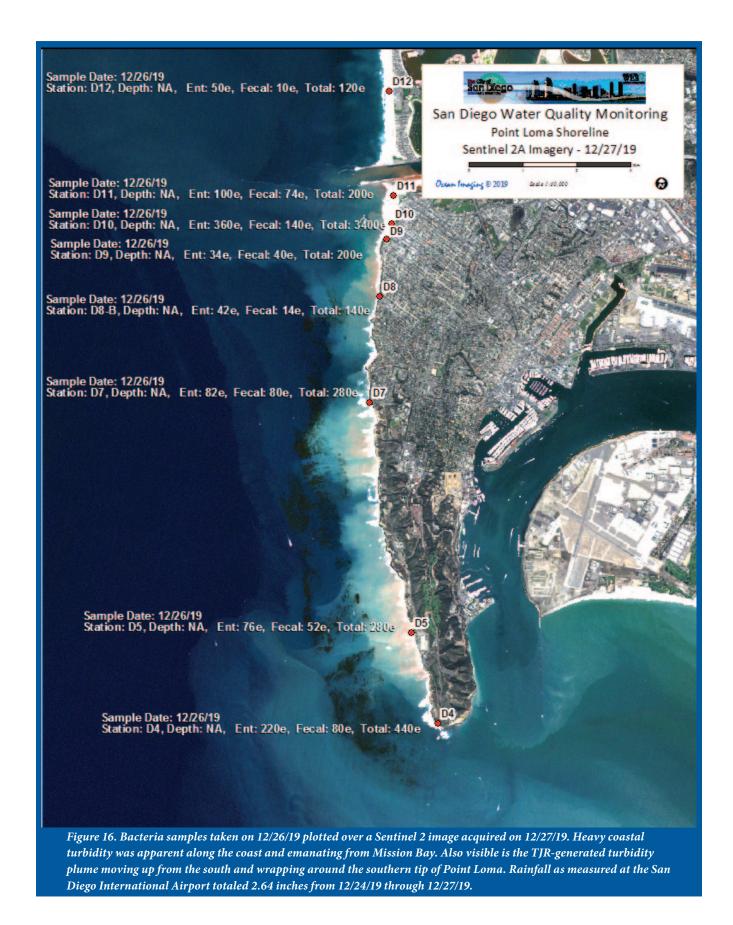


tions are weakened. We believe, however, that on some occasions we have observed the plume's extents indirectly through an anomalous lateral displacement of thermal or chlorophyll features around the outfall wye. This effect can be explained by the doming up of the discharged effluent and laterally displacing the near-surface waters above it.

In 2019 the Point Loma region was affected by conditions already described for the South Bay region: significant seasonal rainfall during the months of January, February, November and December with near zero rainfall during the months of June through August. Similar to past years, this compromised water clarity in the nearshore areas in January through mid-March and from mid-October through the end of December as runoff from the San Diego River and Mission Bay brought sediment-laden water inside and outside the Point Loma kelp bed after the major rain events described above. The "Shoreline", "Kelp" and "Offshore" bacterial sampling resulted in a higher number of elevated bacteria level occurrences than the previous three years. Shoreline field sampling yielded 12 days on which a few of the stations experienced of elevated bacteria levels (as defined by the California Ocean Plan described above). Offshore and Kelp station sampling resulted in 3 and 7 days respectively on which some of these stations recorded high levels. As expected, most of the high bacteria measurements were seen in January through March and November through December and among other factors could be attributed to heavy and/or persistent precipitation events. Figure 16 displays samples taken on 12/26/19 plotted over a Sentinel 2 image acquired on 12/27/19. While no plume associated with the outfall was visible, heavy coastal turbidity was apparent; fueled in part by sediment/turbidity plumes emanating from Mission Bay, a very turbid shoreline on the west side of Point Loma and the TJR-generated turbidity plume which can be seen moving up from the south and wrapping around the

southern tip of Point Loma (exhibited in Figure 8B and discussed below). This turbidity plume can be attributed to the very strong rainfall event between 12/24/19 and 12/27/19. As has been reported in previous years, strong, multi-day northward current episodes after rains can bring contaminated waters from sources in Mexico (e.g. Los Buenos Creek and the Tijuana River) northwestward and occasionally affect the southern Pt. Loma area. This situation was observed three times in the high-resolution satellite imagery on 01/01/19, 11/23/19 and 12/27/19.

One observation provided by the satellite image archive is the continuing variability in the size of the Point Loma kelp bed (Figure 17). Table 4 shows the area in km2 of three notable kelp beds in the San Diego region over the past 12 years. The September and October dates were chosen to represent the kelp bed canopy coverage for each year since spring and fall are considered to be the time periods when the canopy size is thought to be at or near its peak. The size of the Point Loma bed in the fall of (5.17 km2) has increased since its low point in the fall of 2016. As has been reported in previous years, the satellite data show the bed begin to decrease in size during February of 2016, perhaps due to the storm events taking place during early to mid-January or effects from the 2016 El Nino or the Northeast Pacific marine heat wave also referred to as the BLOB. Noted in the 2017 and 2018 annual reports, the kelp bed appeared to be coming back in January of 2017, but then decreased in size as the year progressed resulting in much smaller than average canopy coverage by the end of that year. In 2018, the kelp bed followed a similar interannual pattern. Evident in the table is that the size of the bed in 2019 was larger than the average (4.06 km2) from the previous eleven years. In fact, the average size of the bed during the months of September and October of 2019 was 5.47 km2 – even larger than what is shown in the table. In contrast to 2018 when the Point Loma kelp





bed showed significant interannual variability, the bed remained relatively constant in areal coverage throughout the year in 2019. It is important to point out that the canopy coverages shown in Table 4 may differ slightly from those provided in the Southern California Bight Regional Aerial Kelp Survey reports. This is because the canopy areas for the Point Loma bed computed for those reports are averages of four surveys performed throughout the year and the coverage estimates shown in this report are taken from single satellite images acquired during the fall time period. Tide levels were not a factor in the inter-year comparison as there was little variability in tide level between the years (often approximately one foot or less). However, due to the overflight times of these satellites, the canopy areas could be underrepresented because the tide levels at the time of data acquisition were not optimal for mapping kelp. This may also be another factor if canopy coverage estimates vary between this report and the Southern California Bight Regional Aerial Kelp Survey reports. It is being documented that kelp forests along the West Coast have been in decline in some areas and so this warrants keeping a close watch on

the health of the kelp beds in the San Diego region.

References:

Giles-Guzmán, Alma D., and Saúl Alvarez-Borrego. "Vertical Attenuation Coefficient of Photosynthetically Active Radiation as a Function of Chlorophyll Concentration and Depth in Case 1 Waters." Applied Optics, vol. 39, no. 9, 2000, p. 1351., doi:10.1364/ao.39.001351.

[IBWC] International Boundary Water Commission. (2018-2019). International Boundary and

Water Commission Transboundary Flow Reports, December 2018-March 2019. UnitedStates International Boundary and Water Commission, San Ysidro, CA.

Morel, A., and L. Prieur, 1977: Analysis of variations in ocean color. Limnol. Oceanogr., 22(4), 709-722.

National Weather Service Corporate Image Web Team. "NWS San Diego." National Weather Service, 24 Oct. 2005, w2.weather.gov/climate/index.php?wfo=sgx.

"Southern California Bight Regional Aerial Kelp Surveys." MBC Aquatic, 2020, www.mbcaquatic.com/reports/southern-california-bight-regional-aerial-kelp-surveys.

Svejkovsky, J., N. P. Nezlin, N. M. Mustain and J. B. Kum. 2010. Tracking storm water discharge plumes and water quality of the Tijuana River with multispectral aerial imagery. Estuarine, Coastal and Shelf Science. V87(3), 387-398.

Table 4. Kelp can	opy areas of three San	Diego kelp beds measu	red from satellite im	agery collected for this pr	oject.			
				Kelp (km²)				
Year	Date	Satellite	Point Loma	Imperial Beach	Tijuana			
2019	9/18/2019	Sentinel 2A	5.17	0	0			
2018	10/16/2018	Sentinel 2A	2.44	0	0			
2017	10/4/2017	RapidEye	1.05	0	0			
2016	10/8/2016	RapidEye	0.22	0	0			
2015	9/17/2015	Landsat 8	4.11	0.39	0.29			
2014	9/14/2014	Landsat 8	5.42	0.59	0.3			
2013	9/23/2013	RapidEye	5.89	0.19	0.05			
2012	9/15/2012	RapidEye	2.91	0	0			
2011	9/1/2011	RapidEye	1.99	0	0			
2010	9/27/2010	Landsat 7	6.01	0	0			
2009	9/16/2009	Landsat 5	5.96	1.01	0.21			
2008	9/5/2008	Landsat 7	8.66	0.82	0.01			

APPENDIX A – HIGH RESOLUTION SATELLITE IMAGERY SHOWING SBOO-RELATED WASTEWATER PLUME





